

ILC MAIN LINAC

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- Single-bunch EMITTANCE PRESERVATION in ILC Main Linac
- Main Linac LATTICE Design
- Development of Low Emittance Transport (LET) Study Tools
- Wakefield calculations, Cross-checking codes etc.

1. EMITTANCE PRESERVATION

- ILC Main linac will accelerate e^-/e^+ from $\sim 15 \text{ GeV} \rightarrow 250 \text{ GeV}$

- Upgradeable to **500 GeV**

- Two MAJOR design issues:

- ⇒ **ENERGY** : Efficient acceleration of the beams

- ⇒ **LUMINOSITY** : Emittance preservation



Luminosity Scaling

$$L \propto \frac{\eta_{RF} P_{RF}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\epsilon_y}} H_D$$

- ⇒ **SMALL Normalized Vertical emittance**

- ⇒ **Vertical plane** - more challenging:

- ⇒ Large aspect ratio (x:y) in both spot size & emittance (400:1)

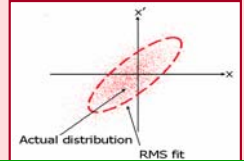
- ⇒ ~ 2 -3 orders of magnitude more difficult

WHAT IS EMITTANCE ?

- Phase space area occupied by beam

- Normalized emittance is invariant in Conservative system

- "RMS normalized emittance" = $\beta\gamma \cdot \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2}$



particles distributed in Phase space

SOURCES OF EMITTANCE DILUTION

- ⇒ Transverse Wakefields:

Single Bunch

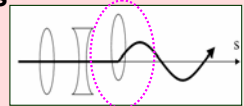
- ⇒ Short Range : Misaligned cavities or cryomodules

- ⇒ Dispersion from Misaligned Quads or Pitched cavities

- ⇒ XY-coupling from rotated Quads

- ⇒ Transverse Jitter

Structure Misalignment



QUAD Misalignment

Nominal Installation Tolerances of components

Tolerance	Vertical (y) plane
BPM Offset w.r.t. Cryostat	300 μm
Quad offset w.r.t. Cryostat	300 μm
Quad Rotation w.r.t. Cryostat	300 μrad
Cavity Offset w.r.t. Cryostat	300 μm
Cryostat Offset w.r.t. Survey Line	200 μm
Cavity Pitch w.r.t. Cryostat	300 μrad
Cryostat Pitch w.r.t. Survey Line	20 μrad
BPM Resolution	1.0 μm

MAIN LINAC DESIGN

- ⇒ 10.5 km length

- ⇒ 9 Cell structures at 1.3 GHz

- ⇒ Gradient: 31.5 MeV/m

- ⇒ Initial Energy spread= 150 MeV

BEAM CONDITIONS

- ⇒ Bunch Charge: 2.0×10^{10} particles/bunch

- ⇒ Bunch length = 300 μm

- ⇒ Normalized initial y-emittance = 20 nm-rad

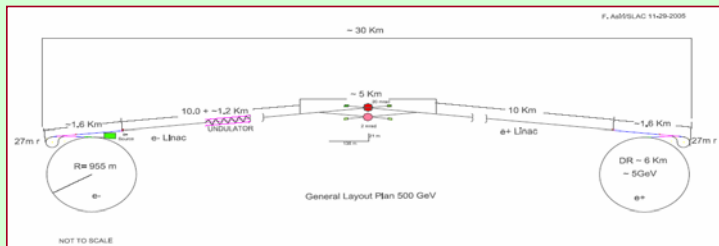
SIMULATION

on behalf of FERMILAB's ILC Main Linac Simulation Group

Paul Lebrun, Leo Michelotti, Shekhar Mishra,

Panagiotis Spentzouris, Alex Valishev

Baseline Configuration Document (BCD)



“The baseline configuration document (BCD) is a snapshot of what we can understand and defend at this time.” - Barry Barish

➤ **TUNNEL** - “Until on-going beam dynamics simulations show otherwise, the linac will follow the curvature of the earth, unless a site-specific reason (cost driven) dictates otherwise.”

➤ **CAVITY** - “31.5 MV/m gradient and Q of 1×10^{10} would be achieved on average in a linac made with eight-cavity CM”

➤ **LATTICE** - “Every 4th CM in the linac would include a quadrupole that also would contain horizontal and vertical corrector windings (this corresponds to a constant beta lattice with one quadrupole every 32 cavities).”

➤ **Cryogenic system** is divided into CryoModules (CM) with 8 RF cavities/ CM

➤ **Magnet Optics** : FODO lattice, with β phase advance of $75^\circ / 60^\circ$ in x / y plane

➤ Each quad has a BPM & Vertical Corrector magnet.

BEAM BASED ALIGNMENT

➤ **Alignment tolerances CAN NOT** be met by *ab initio* installation – need beam-based measurements

➤ **“Beam Based Alignments”**: techniques which provide information on beamline elements using measurements with the beam

⇒ “One-to-One” (1:1) Correction; Dispersion Free Steering; Dispersion bumps, Ballistic Alignment, etc.

➤ **One-to-One (1:1) Steering**

▪ Find a set of BPM Readings for which beam should pass through the exact center of every quad

▪ Use the correctors to Steer the beam

One-to-One alignment generates dispersion which contributes to emittance dilution and is sensitive to the BPM-to-Quad offsets

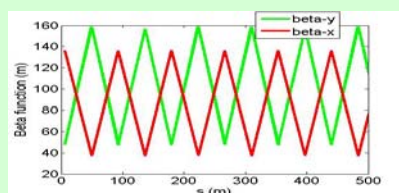
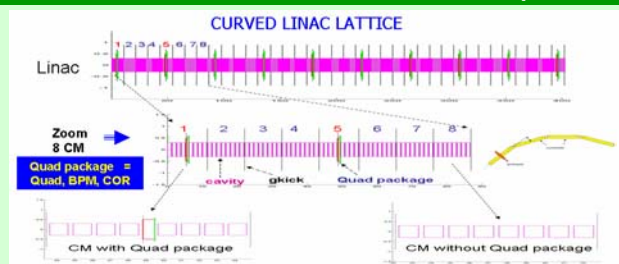
➤ **DISPERSION FREE STEERING (DFS)**: DFS is a technique that aims to directly measure and correct dispersion in beamline

▪ Measure dispersion (via mismatching the beam energy to the lattice)

▪ Calculate correction (via steering magnets) needed to zero dispersion and apply the correction

⇒ Successful in rings (LEP, PEP) but less successful at SLC (Two-beam DFS achieved better results) (Note: SLC varied magnet strengths (center motion?))

SIMULATION USING MAT-LIAR (Linear Accelerator Research Code)



Beta functions vs. linac length (s)

- **Modifications in LIAR @FNAL** to simulate the curvature:
 - The curvature is simulated by adding kinks b/w the CM
 - The matched dispersion condition at the beginning of the linac can now be artificially introduced into the initial beam

Length (m) : 10.4 km
 N_quad : 240
 N_cavity : 7680
 N_BPMs : 241
 N_Xcor : 240
 N_Ycor : 241
 N_gkicks : 1920

DISPERSION FREE STEERING (DFS)

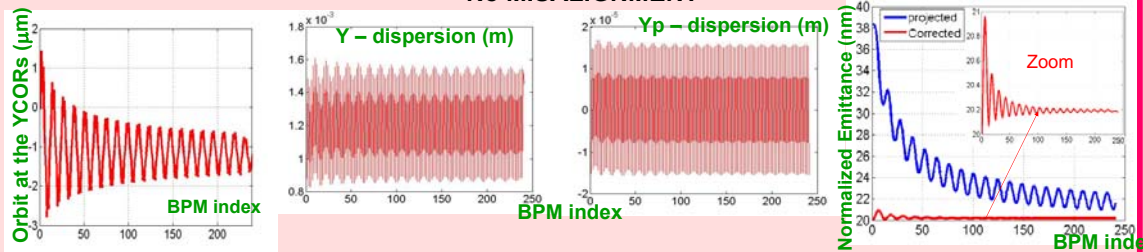
- Divide linac into segments of ~40quads
- Two orbits are measured
- Vary energy by switching off cavities in front of a region
- Measure change in orbit & apply correction
 - ⇒ Constraint - simultaneously minimize dispersion and RMS of the BPM readings
- Iterate twice before going to the next segment
- Performed for 50 Seeds

ONE-TO-ONE STEERING

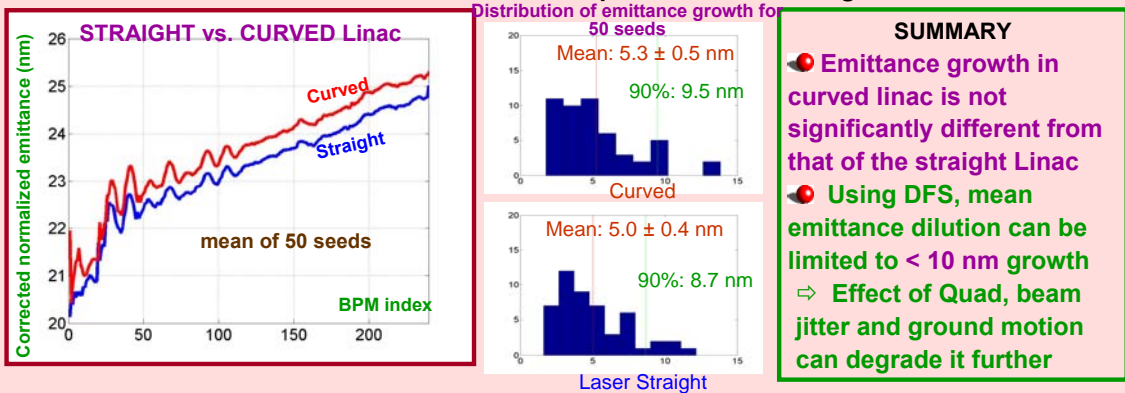
- Divide linac into segments of ~50 quads/segment
- Read all Q-BPMs in a single pulse
- Compute set of corrector readings and apply the correction
 - ⇒ Constraint – minimize RMS of the BPM readings
- Iterate few times before going to the next segment
- Performed for 50 Seeds

RESULTS

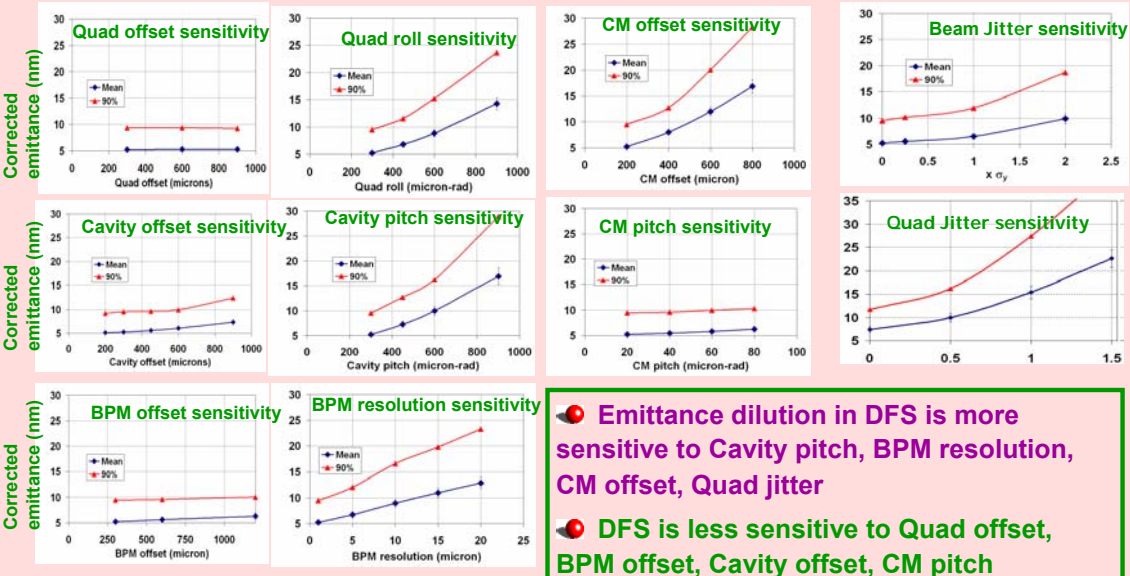
No MISALIGNMENT



NOMINAL MISALIGNMENTS – Dispersion Free Steering – 50 seeds



Sensitivity studies – keeping other misalignments constants, vary one particular misalignment from its nominal value



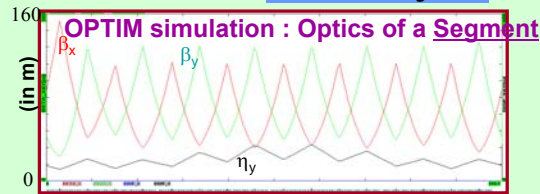
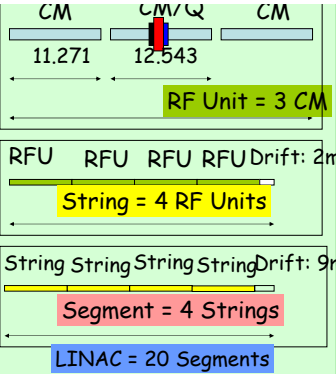
2. LINAC LATTICE DESIGN

- 1 RF unit in ILC (BCD) powers 3 cryomodules and so it would be interesting to explore the possibility to have 1Q/ 3CM instead of 1 Q/ 4CM
- Include realistic drift spaces in the lattice and match the lattice

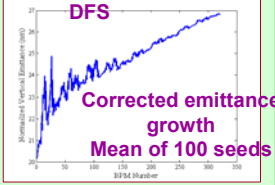
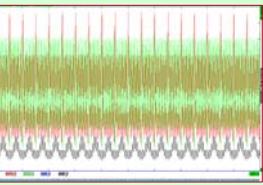
1 Quadrupole per 3 Cryo Modules = RF Unit (35 m)

Cold drift of 2 m at the end of a String (142 m)

Warm diagnostics section of 9 m at the end of a Segment (578 m)



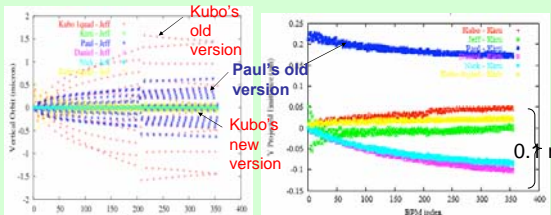
Optics of the entire LINAC



3. CROSS-CHECKING CODES

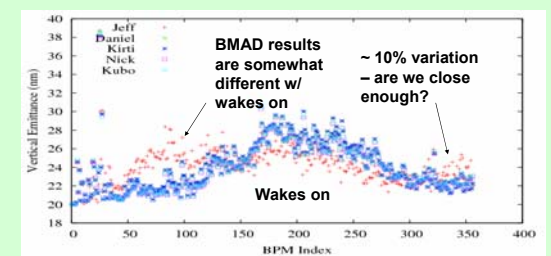
- Different codes used for emittance preservation - BMAD (TAO), PLACET, MERLIN, SLEPT, MATLIAR, CHEF –exercise #1
- compared by different people at CERN, DESY, Cornell, KEK, SLAC and FERMILAB

EX# 1: In perfectly aligned LINAC (TESLA lattice), launch the beam with the initial y-offset of 5 μm (including TESLA wakes)



Difference in the vertical orbit at the BPMs w.r.t. BMAD

PT (SLAC) generated the Misalignments file (for Quads, BPMs and cavities) using MATLIAR and also the vertical corrector's setting for the DFS EX # 2: Include the misalignments and the vertical corrector's setting and plot the emittance dilution



4. Low Emittance Transport Tools Development

CHEF (by Leo Michelotti & Francois Ostiguy, FNAL)

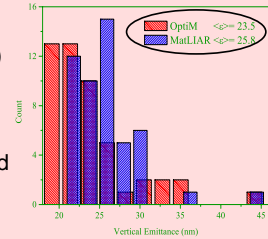
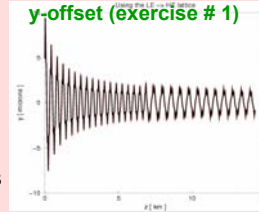
- Interactive program for accelerator Optics
- Uses high level graphical user interfaces to facilitate the exploitation of lower level tools incorporated into a hierarchy of C++ class libraries.

Used for circular machines and transfer lines, now upgrading for ILC studies

OptiM (V. Lebedev, FNAL)

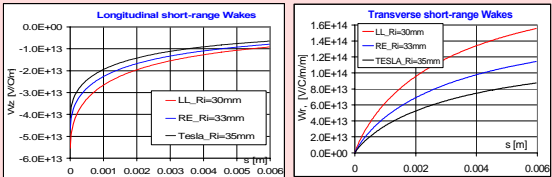
- Used for more than 10 years
- Integrated system for Optics design, support and measurement analysis
- Similar to MAD but with integrated GUI
- Wake fields, tracking
- No beam based alignment features yet

Y-orbit comparison b/w MERLIN and CHEF for 5 μm initial y-offset (exercise # 1)

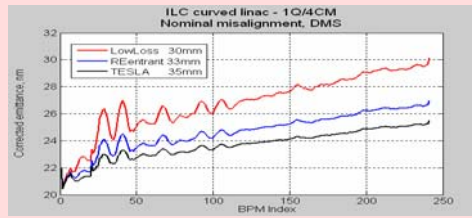


Emittance dilution in MatLIAR and OptiM with 1 μm Quad misalignments in Curved ILC Linac

5. WAKEFIELD CALCULATIONS



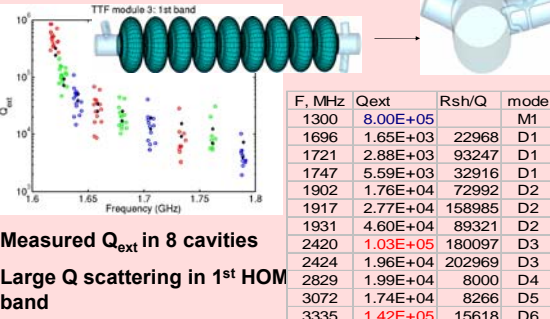
Corrected Emittance Dilution vs. BPM index for different wakefields



6. HOM STUDIES

Preliminary results of Multi-bunch emittance preservation indicate that the effect of random frequency errors is extremely beneficial! However, attention must also be paid to modes trapped in cavity. These can lead to a large emittance dilution! (R. Jones)

- What we are doing:
 - R/Q and Q_{ext} for a few first pass bands in real solid model
 - Q_{ext} scattering due to cavity imperfections and inter-cavity spacing
 - Optimization (new design) of HOM coupler



F, MHz	Qext	Rsh/Q	mode
1300	8.00E+05		M1
1696	1.65E+03	22968	D1
1721	2.88E+03	93247	D1
1747	5.59E+03	32916	D1
1902	1.76E+04	72992	D2
1917	2.77E+04	158985	D2
1931	4.60E+04	89321	D2
2420	1.03E+05	180097	D3
2424	1.96E+04	202969	D3
2829	1.99E+04	8000	D4
3072	1.74E+04	8266	D5
3335	1.42E+05	15618	D6